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THERMOMAGNETIC TORQUES IN POLYATOMIC GASES

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The aim of the work done for the duration of this grant was to study the Scott effect[1] with specific emphasis on determining the applicability of the Scott effect to the dynamics of stellar and galactic rotation. Very simply stated, one would like to determine the force acting on each volume element of the gas as a function of the distance to the center of the system, the gas pressure, the radial thermal gradient, and the vertical magnetic field. The effects of the thermomagnetic torque on a particular system (such as galaxies or stars) could then be determined by using parameters appropriate for the system under consideration. Progress has been made toward attainment of the final goal. The work is continuing under NASA Grant NGR 44-005-137 and we feel the goal will be attained.

The work has proceeded according to the following scheme; modification of experimental apparatus to improve sensitivity and stability of torque measurements, efforts to understand the microscopic mechanism which produces the Scott effect, and formulation of the problem to include treatments of stellar and galactic systems. The remainder of this report will be devoted to a discussion of these aspects of the work.

From the data taken with our present apparatus (see the Interim Progress Report dated January 1, 1971 - June 30, 1971 for a detailed description of the apparatus), it has been established that several changes needed to be made. In order to achieve greater stability, the temperature of both the inner and outer cylinder had to be controlled and measured. This change is being effected by heating the inner cylinder by optical radiation incident on an absorbing surface. Its temperature will be measured by a platinum resistance thermometer in a bridge circuit. The temperature of the outer cylinder is controlled by use of a water jacket. No change is being made in this approach. In order to reduce field independent torques (which have been observed by others[2], but not explained), asymmetries in the system had to be removed. This change is being effected by constructing the water jacket and outer cylinder out of glass. This eliminates the need for any glass ports which disrupt the cylindrical symmetry and give rise to the field independent torques. These field independent torques were previously conjectured to be caused by coriolis forces, but have since been found to be a result of Knudsen effects. A draft of a paper which explains these field independent torques and is to be submitted to Physics of Fluids for publication is enclosed as part of this report. The final change which has been made is the replacement of the solenoid by Helmholtz coils to give greater magnetic field homogeneity.

A brief summary of our present understanding of the Scott effect from a microscopic viewpoint is as follows:

(1) If one tries to transform rotational angular momentum to circumferential angular momentum, the torque involved is

only 10^{-3} of the observed Scott effect torques. (2) One might try to increase the total torque by increasing the collision frequency. This would involve introducing an anomalous collision cross section which is not observed experimentally. Support for the previous statement lies in the fact that the expression for the field at which the maximum torque occurs (H_{max}) is given by $H_{max} = a(P+b)$, where a and b depend on the cross section. No anomalies in a and b are noted. (3) One therefore looks for an anistropic differential cross section for scattering of rotating dipoles in a magnetic field to get the net change in angular momentum. (4) For the pressures at which the Scott effect is observed, binary collisions must account for the effect. Therefore, one needs to calculate the angular momentum transfer between two colliding rotating dipoles in a magnetic field and evaluate the differential cross section for the collision. The resulting torque T could be expressed as

$$T = \frac{\int (\Delta L)_{collision}\,(d\sigma/d\Omega)d\Omega}{\int (d\sigma/d\Omega)d\Omega}\left(\frac{1}{\tau_0}\right),$$

where ΔL is the angular momentum transferred per collision, $(d\sigma/d\Omega)$ is the differential scattering cross section, and τ_0 is a characteristic ralaxation time for correlated scattering in a magnetic field. (5) The functional form of τ_0 can be estimated as follows. For a dilute gas the system will not be far from equilibrium and the single particle distribution function for a molecule would be of the form

$$f = f_0 e^{-t/t_1},$$

where f_0 is the equilibrium distribution function ant t_1 is the collision time ($1/t_1 = \sigma\rho v$). If the fourier transform of e^{-t/t_1} is computed to be

$$\mathrm{Re}\int_0^\infty e^{-t/t_1}e^{i\omega t}dt = \frac{1/t_1}{(1/t_1)^2+\omega^2}$$

and ω is identified as the frequency in the system with which the collisions must compete (the Larmor frequency in this case), then

$$1/\tau_0 \propto \frac{\omega_c t_1}{1+(\omega_c t_1)^2}\ .$$

Since $\omega_c \propto H$ (magnetic field) and $t_1 \propto 1/P$, then

$$\frac{1}{\tau_0} = f(H/P).$$

The torque measured in the Scott effect has the functional form given above. (6) The preceding arguments suggest that the quantity of interest in the Scott effect from a first principle point of view is the differential scattering cross section. At the present time we are in the process of evaluating the integrals involving ΔL and $d\sigma/d\Omega$.

As previously stated, the ultimate goal of this work is to study galactic and stellar dynamics which might be caused by the Scott effect. So far this work has consisted primarily of gathering evidence to support our position that the Scott effect may be applicable to stellar and galactic systems. The points are listed below:

(1) It is known that stellar systems are composed primarily of molecular hydrogen which does show a Scott effect.

(2) Thermal gradients are produced by gravitational contraction.

(3) Stellar magnetic fields are large enough to cause observable Scott effects.

(4) At some time in the formation of a star, the gas pressures will be of the right order of magnitude for the Scott effect to be of some importance.

REFERENCES

1. G. G. Scott, H. W. Sturner, and R. M. Williamson, Phys. Rev. 158, 117 (1967).

2. T. W. Adair, Private communication.